Management Implications and Planning for Effective Salmon Enhancement in Mixed Wild and Enhanced Fisheries

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Abstract

When hatchery stocks are created under a policy of supplementing rather than displacing wild production they will create a unique management challenge if they mix with established stocks of the same species in fisheries that are managed largely on catch data. The challenge results because managers have to estimate the portion of the harvest that are wild stocks. This new variable is subject to estimation error that may significantly impair the manager's ability to achieve the desired escapement goals for the wild stocks. Through quantitative approximations, we found that, even if the error in the wild stock proportion estimate is small, it can significantly effect escapements when the portion of the hatchery stock in the fishery is relatively high. Attendant increases in escapement variation could reduce both harvest opportunities and wild stock production. Options to circumvent this problem include (1) basing management decisions on information other than harvest data, (2) distinguishing hatchery and wild portions of the harvest through tag/mark programs or scale reading, (3) altering enhanced stock timing so it avoids the period when wild stocks are prevalent in the fishery, (4) relocation of fishing effort to stock-specific terminal areas, and (5) limiting of hatchery production to levels that minimize detrimental impacts. The first three options may be the least objectionable, but the last two options may be the only reasonable solutions in some situations; the merits and shortcomings of each are discussed.

Exploitation potentials for hatchery stocks of Pacific salmon *Oncorhynchus* are generally greater than they are for wild stocks because hatchery stocks usually display higher egg-to-adult survival rates. Consequently, management choices have to be made to harvest returning hatchery stocks at levels that commingled wild stocks can withstand or at levels that the hatchery stocks can withstand (Larkin 1974; Ricker 1975; Wright 1981; Hankin 1982). Some states and countries have chosen the latter and written off wild production in favor of massive hatchery stock programs: e.g., Washington State in the Columbia River, Quinault River, and Willapa Bay coho salmon *O. kisutch* fisheries (Wright 1981) and Japan (Moberly and Lium 1977). Arguments have also been made in favor of protecting and maintaining wild stocks (e.g., Helle 1981; Wright 1981).

In the 1970s Alaska embarked on a major salmon enhancement program under a general policy aimed at maintaining wild stock production over the short term and increasing it over the long term (ADF&G dateless; State of Alaska 1974; ADF&G 1975; NSRAA 1982). New salmon stocks were developed primarily through standard salmon hatchery ranching practices (McNeil and Bailey 1975). Surplus returns to hatcheries were expected because the mixed stock fisheries through which the hatchery fish would pass were to be managed primarily for the less productive wild stocks (ADF&G 1975). Through careful planning most hatcheries were located in bays of sufficient area to hold terminal fisheries on segregated hatchery returns. These segregated terminal fisheries were to provide opportunities to complete the harvest of hatchery fish not taken in the mixed stock fisheries.

A more complicated aspect of planning for hatcheries required identification of fisheries in which hatchery returns might confuse the estimates of wild stock run strength and thereby complicate management (NSRAA 1982). Fisheries managed on forecast or escapement information were not a problem because these management data generally provide estimates of wild stock run strength uncomplicated by hatchery stock run strength. However, where catch data were used to manage the fishery, potential difficulties were expected, but only if the hatchery stock (1) was the same species as the wild stocks managed in the fishery, and (2) was present at the same time the fishery was prosecuted on the wild stocks.

These fisheries were potential problems because the catch data or catch per unit effort (CPUE) on which the fishery was managed could be affected by the presence of hatchery fish. To continue to manage the fishery based on wild stock run strength, the manager would have to estimate the CPUE for just the wild stocks.

Imprecise estimates represented a new source of management error that could compromise a manager's ability to provide desired harvests and escapements. Although widely perceived as a new management problem, the potential threat from imprecise hatchery-wild stock proportion estimates on resulting escapements had not been quantitatively demonstrated. Therefore, the severity and likelihood of this problem provoking losses in production and harvests became a matter of personal opinion and contentious debate during the late 1970s and early 1980s.

We believed the potential impacts of this error on escapements could be mathematically depicted and, as part of hatchery planning efforts (NSRAA 1982), developed quantitative approximations that described the risks to escapements. This provided an objective planning base on which hatchery production objectives and pragmatic management strategies were developed that minimized or circumvented risks. This paper formally presents and updates that initial working document prepared for the planning effort.

DERIVATION OF ESCAPEMENT ERROR

The new error source associated with estimating the hatchery percentage of the harvest we called the estimated contribution error or ECE. If the manager makes an ECE, his mistake will affect the escapement achieved. The greater the ECE, the greater its effect on escapement.

In most cases managers do not estimate the total return population, S, as a point estimate but use escapement or catch indices to provide an indication of run strength. Through years of experience they have determined about how much fishing effort can be exerted on a run with that run-strength index and still meet the escapement goal, G. When hatchery stocks affect the CPUE indicators of S, the manager, accepting the estimated proportion of the wild stocks in the fishery, e, as his best estimate of true proportion, t, will estimate the wild stock CPUE with e(CPUE). This estimate becomes his best indicator of wild stock run strength, $e(S)$, and serves as the basis for determining the allowed harvest. The resultant the exploitation rate, r, is

$$r = (eS - G)/eS. \tag{1}$$

For simplicity, assume no other error sources exist in the management strategy outside of the possible difference between e and t. The escapement goal is met if $e = t$. When $e \neq t$ there is an ECE (or $t - e$) that produces an escapement error, E:

$$\begin{aligned} E &= A - G \\ &= (1 - r)S - (1 - r)eS \\ &= (1 - r)\,S\,(t - e)\,, \end{aligned} \tag{2}$$

where A = realized escapement for the wild stock. E reduces or increases the escapement that would have been achieved had there not been an escapement error. When E occurs it can be converted into a percent deviation in the under- or over-escapement, D, as follows:

$$\begin{aligned} D &= 100[(A-G)/G]\% \\ &= 100[(1 - r)\,S\,(t - e)]/[(1 - r)eS]\% \\ &= 100\,(t - e)\,/\,e\,\%\,. \end{aligned} \tag{3}$$

Table 1 provides examples of percentage deviations, D. These examples show that the larger the contribution of the hatchery stock to the fishery, the greater the effect of an ECE on wild stock escapements, again assuming for simplicity that management would, without the ECE, have achieved the escapement goal. If, for example, wild and hatchery stocks each composed 50% of the fishery population (t = 50%) and if the wild stock contribution level, e, was estimated to be 60%, then because of the -10% ECE (i.e., $t - e$), the wild stock escapement would have been 17% below goal. If e erred in the other direction and was 40% (+10% ECE), then 25% fewer fish would have been harvested, leading to a 25% overescapement. A 10% ECE, however, translates into a much larger impact on management error as the hatchery contribution increases. For example, if t was 20% and e was 30% (-10% ECE), then the wild stock escapements would have been 33% below goal instead of 17% (as produced by the -10% ECE when t was 50%). Therefore, as the hatchery contributions to fisheries increase, the potential impacts on management and risks to wild stock production become much more serious.

Also, larger ECEs produce greater impacts on escapements. Referring to the last example (t = 20%), if e was 40% rather than 30%, the -20% ECE would have reduced escapements by 50%

rather than by 33%. This indicates that contribution estimates need to be fairly accurate, especially when hatchery contributions approach 50% or more.

By supplying actual escapement goals (G) and by varying percentage deviations (D) shown in Table 1, numerical escapement errors (E or actual over or underescapements) can be calculated: $E = DG/100$.

EFFECT OF ECEs ON ESCAPEMENTS

In Alaska, fisheries targeting on mixed stocks are sometimes managed to meet a single escapement goal represented by the sum of individual stream goals for each contributing stock. Escapements from such fisheries may meet the cumulative escapement goal without meeting the individual stream goals. That is, over and underescapements may occur in individual streams that accumulatively sum to the overall combined goal.

If an ECE was made that resulted in a lowering of the cumulative escapement from the fishery by 20%, then even if the stocks are randomly distribution within the fishery, all the individual stock escapements would not be equally affected. The percent deviation, D, between a realized escapement and its goal (equation 3) can be used to show this effect. The effect on the individual stream escapements can be measured by

$$D_2 = D_1 + Y[1 + (D_1/100)], \tag{4}$$

where:

D_1 = the percent deviation in escapement for a given stock contributing salmon to a mixed stock fishery that has resulted from management error sources other than an ECE (no ECE made),

D_2 = the same situation described for D_1 except that an ECE is additionally made, and

Y = the difference between D_3 and D_4, i.e., $(D_3 - D_4)$, where D_3 the percent deviation resulting for all the stocks in the mixed stock fishery (of which D_1 is a part) cumulatively treated as one conceptual stock and resulting from management error sources other than an ECE (no ECE made) and D_4 is the same situation as D_3, except that an ECE is additionally made.

A stream that would have been 30% underescaped ($D_1 = -30$) would be 44% underescaped ($D_2 = -44\%$) if an ECE was made that effected a 20% reduction in the cumulative escapement ($Y = -20$). The stream that was 60% overescaped would be 28% overescaped when $Y = -20$. In another year, however, Y could just as easily be +20%, assuming ECEs are normally distributed around a mean of zero.

REDUCTION IN MANAGEMENT PRECISION

If ECEs are normally distributed, it is quite possible that EECs associated with hatchery stocks may not affect the average deviation from the wild stock escapement goals attained over the management history of the fishery. In other words, if a manager using CPUE to manage a fishery had, over the years, obtained an average escapement that was 90% of the cumulative goal, the addition of hatchery-related ECEs might not greatly alter the 90% average.

However, even if the average remains unchanged, an increase in the escapement ranges and standard deviation around the 90% mean is likely and that increased variability could damage production and future harvests. For example, a fishery that is managed between 80 and 150% of its cumulative escapement goal is more precisely managed than a fishery with a range between 60 to 170% of the goal, even though the average is 90% in both situations.

A convenient measure of precision is the percent coefficient of variation (CV = 100 x standard deviation/mean). If the combined stream escapement goal from a fishery was 100,000 fish and the standard deviation of the recorded escapements yielded a coefficient of variation that equaled 10%, then about 95% of the time the escapement is between 80,000 and 120,000. But if a hatchery stock is added to the fishery, the manager is now forced to estimate the proportion of the established stock (*e*), which he can do only with a certain level of precision. That precision can also be measured by its own coefficient of variation.

This additional source of variation will reduce the manager's precision: The new standard deviation around the yearly recorded escapement mean becomes approximately

$$\blacklozenge = eS\sqrt{C^2 + C_e^{\,2}} \qquad (5)$$

where:

- C = the coefficient of variation for the recorded escapements before the introduction of the hatchery stock, and
- C_e = the coefficient of variation of manager's estimates of percent established stocks.

Because of the additional variation in estimating e, where the new C_e is 10% and C is 10%, the 95% confidence interval would widen to 70,000 - 130,000. The example assumes that, over the history of the fishery, fishable surpluses always occurred and that all underescapements were due to the management error rather than inadequate returns. Had such deficiencies in returns occurred it would not alter the implications of the example, but it would needlessly complicate the mathematics.

Table 2 gives the expected percent increase in the standard deviation of selected wild stock escapements by the coefficients of variation C_e and C. The increase is negligible only when C_e is small in comparison with C before the new stock is added. In other words, when a new stock is developed to contribute to a fishery that previously sustained a relatively high coefficient of variation for recorded escapements, the hatchery stock ECEs will not affect escapement variability as much as it would if the fishery had been more precisely managed (lower C). Additionally, the greater the coefficient of variation of the ECEs, the greater becomes the impact on the wild stock escapement variability.

DISCUSSION

Non-uniform survival rates and attendant harvest potentials among wild stocks contributing to a mixed stock fishery often vary, making it difficult for managers to effect the proper harvest level and escapement for each wild stock (Larkin 1981). This, however, should not be construed to mean that, for mixed stock fisheries managed on catch data, the additional error source inherent in estimating wild-hatchery proportions, *e*, is inconsequential and can be ignored. To do so would threaten wild stocks and inevitably reduce potential harvests of those stocks.

How much worse depends on how well the fishery was previously managed (see equation 5 and Table 2), the magnitude of the hatchery contributions to the fishery, and the precision with which *e* is likely to be estimated. If the fishery has been poorly managed, the impact of ECEs may be negligible provided hatchery contributions are low or *e* is reliable. If *e* is unreliable, the resulting large ECEs may greatly reduce management control, even if previous escapements varied widely. Therefore, if hatcheries are to supplement rather than displace wild salmon production, the problems associated with ECEs must be addressed. Five different types of solutions for ECE problems are possible; they are not necessarily exclusive and can be combined as necessary and appropriate to protect wild stocks and ensure maximum benefits from hatchery production.

Option 1. Switch Data Base: In some cases, the need to enhance harvests in certain areas may stimulate attendant increases in management budgets and permit an alternative management database to be developed. If such data provides estimates of the wild stock run strength unbiased by the hatchery stock, the ECE problem could be avoided. Forecasting, for example, might be used, but its accuracy is currently limited. Escapement data, while generally reliable, might be used, but it may not be feasible in fisheries that precede the time when spawners can be enumerated in or near their natal streams. Escapement data can also be expensive to collect when there are a large number of remote streams to be surveyed under sometimes hazardous weather conditions.

Option 2. Hatchery and Wild Stock Sorting: Holding ECEs to minimal levels may be facilitated in some cases by sampling the catch and enumerating its wild and hatchery components. The use of tags to estimate catches by stock has been discussed by Paulik and Robson (1969), Hankin (1982), and Geiger (1989). Scale reading might also facilitate reasonably accurate distinction between wild and hatchery stocks (Scarnecchia and Wagner 1980; Van Alen 1988; Cross and Straton 1989). While tag/mark programs and scale reading may be useful in small, slow-harvest fisheries, their application to fisheries that harvest comparatively large numbers of fish over short periods appears negligible at present. Time required to sort and process a statistically valid sample may be great, especially when only a few days are available before the next management decision is required. Accurate estimates may be further compromised by inability of hatcheries to mark all or a large portion of the returns. Marking only a proportion of the release requires expansion of recovery data to include the unmarked portion, and the expansions induce additional error. Tag-induced mortality and tag loss exacerbate problems in providing a reliable *e* (Clark and Bernard 1987). Technological advancements in marking and recovery may eventually lessen or remove these barriers.

Table 1 can assist development of tag/mark recovery plans. First, managers would consider and specify, on a percentage basis, the increase in underescapements and overescapements they can accept. Then, based on the expected average hatchery contribution to the fisheries, Table 1 or equation (3) would be used to approximate the ECE that would produce those underescapements and overescapements. Finally, this ECE level would be used to assign confidence intervals and precision compatible with that ECE level, which in turn would be converted into the necessary sample size. The manager's ability to provide wild stock escapements might also be examined in relation to Table 2 because poorly managed fisheries can withstand greater ECEs without greatly reducing management effectiveness. In this way statistical accuracy and precision can be tailored to meet different fishery situations.

Option 3. Modify Timing of Hatchery Stock: In some cases it may be possible to manipulate hatchery stock run timing to temporally precede or follow the established fishery; i.e., the number of hatchery fish entering the established fishery would be negligible or so low that impacts on management would be modest. Difficulty in engineering run timing and extended periods of wild stock presence in many fisheries may limit use of this option.

Option 4: Relocate Fishing Effort: In situations where options 1-3 are infeasible, it may be possible to protect established stocks by skewing EECs to favor the established stocks (i.e., use a minimal *e* value). This should limit fishing effort to levels that would prevent overharvest of the wild stocks in even their weakest survival years. Under this strategy the fishery would not fully harvest most stocks at the traditional location, and fishing effort would have to be relocated to terminal segregated areas where each wild and hatchery stock could then be additionally harvested on a stock-by-stock basis. Fish quality, and hence price, may be lower in terminal areas. Gear groups participating in the mixed stock fishery may, by regulation, be excluded from participating in the terminal fisheries. *De facto* devaluation or reallocation of the fishery as a management by-product would not be favorably received by gear groups. This option may therefore be useful only when the mixed stock and terminal fisheries are open to the same gear types.

Option 5. Limited Hatchery Production: When options 1-4 are infeasible, planners may have to restrict hatchery production to levels that would provide fishery enhancement without too greatly jeopardizing the established stocks. It is a compromise situation that must balance the need for increased harvests against acceptable risk to natural production. In Alaska, for example, a hatchery planning committee wrestled with this problem as it related to the pink salmon *O. gorbuscha* seine fishery in northern Southeast Alaska. The committee elected to set a minimum t of 75% or a 25% maximum average contribution level for hatchery pink salmon stocks in that fishery (NSRAA 1982). Limits such as this may or may not actually constrain hatchery production: it depends entirely on the numbers of wild stock salmon in the fishery and the increased numbers of salmon wanted by the fishing industry. For example, chum salmon *O. keta* in Southeast Alaska are managed on the basis of pink salmon run strength and therefore chum salmon did not pose ECE problems. Also, chum salmon were generally more desired by the fishing industry, so chum salmon provided a better alternative than pink salmon, and the limit on pink salmon production, therefore, was not a pragmatic encumbrance.

All of these options are being used in Alaska's salmon enhancement program with varied success. Switching from management based on catch data to alternative data has been the least utilized option. Tagging/marking seems to be receiving the greatest attention and is most widely touted as the most promising solution. However, coded wire tagging has not yet demonstrated that it can provide estimates of hatchery contributions that are timely and accurate enough to maintain satisfactory management control. Furthermore, the prevailing belief that 90 to 95% confidence intervals around e would be acceptable for management may be myopic because at very low levels of t, even small ECEs could greatly reduce management effectiveness. Therefore, the best overall strategy recognizes the need for all these options to be applied in creating area-by-area, species-by-species, and year-by-year plans that will ensure a vital role for salmon enhancement in Alaska without jeopardizing its wild stocks.

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Table 1. Percentage deviations in escapements caused by example ECEs. An ECE occurs when the actual percent of wild stocks in the fishery is different than the estimated percent (i.e., when $e \neq t$). When no ECE occurs, the percent deviation = 0).

Estimate (e)	Actual percent of the wild stocks in the fishery (t)								
	10	20	30	40	50	60	70	80	90
10	0	100	200	300	400	500	600	700	800
20	-50	0	50	100	150	200	250	300	350
30	-67	-33	0	33	67	100	133	167	200
40	-75	-50	-25	0	25	50	75	100	125
50	-80	-60	-40	-20	0	20	40	60	80
60	-83	-67	-50	-33	-17	0	17	33	50
70	-86	-71	-57	-43	-29	-14	0	14	29
80	-88	-75	-63	-50	-38	-25	-12	0	12
90	-89	-78	-67	-56	-44	-33	-22	-11	0

Table 2. Percentage increase in the standard deviation of escapements obtained from established fisheries resulting from an additional management variable (C_e). C_e will occur if the portion of wild stocks in the fishery must be estimated (*e*) and if errors in making those estimates (ECEs) occur.

CV for the recorded escapements (C)	CV for the estimates of the wild stock proportions in the fishery (C_e)				
	2	5	10	15	20
2	40	170	410	660	900
5	8	40	120	215	310
10	2	10	40	80	125
15	1	5	20	40	65
20	0	3	10	25	40